Chapter 7
Desktop Analysis

This chapter describes three case studies aimed at assessing the cost-effectiveness of sewer flushing technology from different performance perspectives These performance perspectives are minimization of maintenance costs, reduction of sediments CSO first flush, and reduction of sediments to lower hydrogen sulfide levels. The first case study utilizes information developed for Fresh Pond Parkway Sewer Separation and Surface Enhancement Project in Cambridge, MA. A cost analysis was performed in this case study to compare flushing technologies versus conventional sewer cleaning methods. The second case study uses the desktop procedure described in Chapter 3 to investigate the pollution control effectiveness for a typical Northeast combined sewer catchment. The number of combined sewer overflows was determined using long term flow measurements. A cost analysis was performed to investigate present worth costs of satellite treatment versus flushing technology. The last case study investigated the cost effectiveness of sewer flushing versus chemical addition for hydrogen sulfide control.

Case Study One: Fresh Pond Parkway Sewer Separation and Surface Enhancement Project Storm and Sanitary Sewer Flushing

In Chapter 5, different methods of manual cleaning are presented which are costly and maintenance intensive. In this case study, the cost effectiveness of sewer flushing, utilizing flushing gates, versus periodic manual cleaning and sediment removal is investigated.

Over the last twenty years, the City of Cambridge has aggressively separated old combined and over and under sewerage systems throughout the City to enhance drainage service and to improve the water quality in the Alewife Brook and the Charles River. Presently, the City is in the construction phase of separating the CAM 004 area (25 hectares, 250 acres,) catchment. This area is north and west of Harvard Square and within dense heavily traveled urban regions.

Grit deposition within both sewerage and storm drainage systems is a major problem because of general flatness of the area, presence of several shallow streams that the sewerage (storm and sanitary) systems must cross under as siphons, and the hydraulic level of the receiving water body that frequently backwaters the storm systems. To overcome this problem in the CAM 004 area, automated flushing systems using quick opening (hydraulic operated) flushing gates to discharge collected stormwater will flush grit and debris to downstream collector grit pits.

Description of Piping Systems to be Flushed

The storm and sanitary sewer systems to be flushed are located within the CAM 004 catchment area. These systems start on the Fresh Pond Parkway near the Cambridge water treatment plant, continue east to the Concord Circle and then northeast to the Fresh Pond Circle. Both systems then proceed down Wheeler Street under the MBTA/Conrail railroad tracks and terminate near the Alewife Parking Garage. The piping systems consist of approximately 1400 m (4,666 ft) of sanitary trunk sewers, ranging from 460 mm to 1.2 m (18 inch to 48 inches), and approximately 1620 m (5,400 ft) of existing storm drains with pipe sizes ranging from 600 mm (24 inches) to 1.2m by 1.8 m (4 ft by 6 ft). There is a major overflow into the Alewife Brook from the sanitary sewer system just beyond the Alewife Parking Garage.

Two construction contracts have been prepared for the overall sewer separation and surface enhancement project along the Fresh Pond Parkway between Huron Avenue and Fresh Pond Circle. Flushing systems are included in one of the two construction contracts. Construction startup is expected in September 1998. Figure 7-1 depicts the general locations of the flushing vaults.

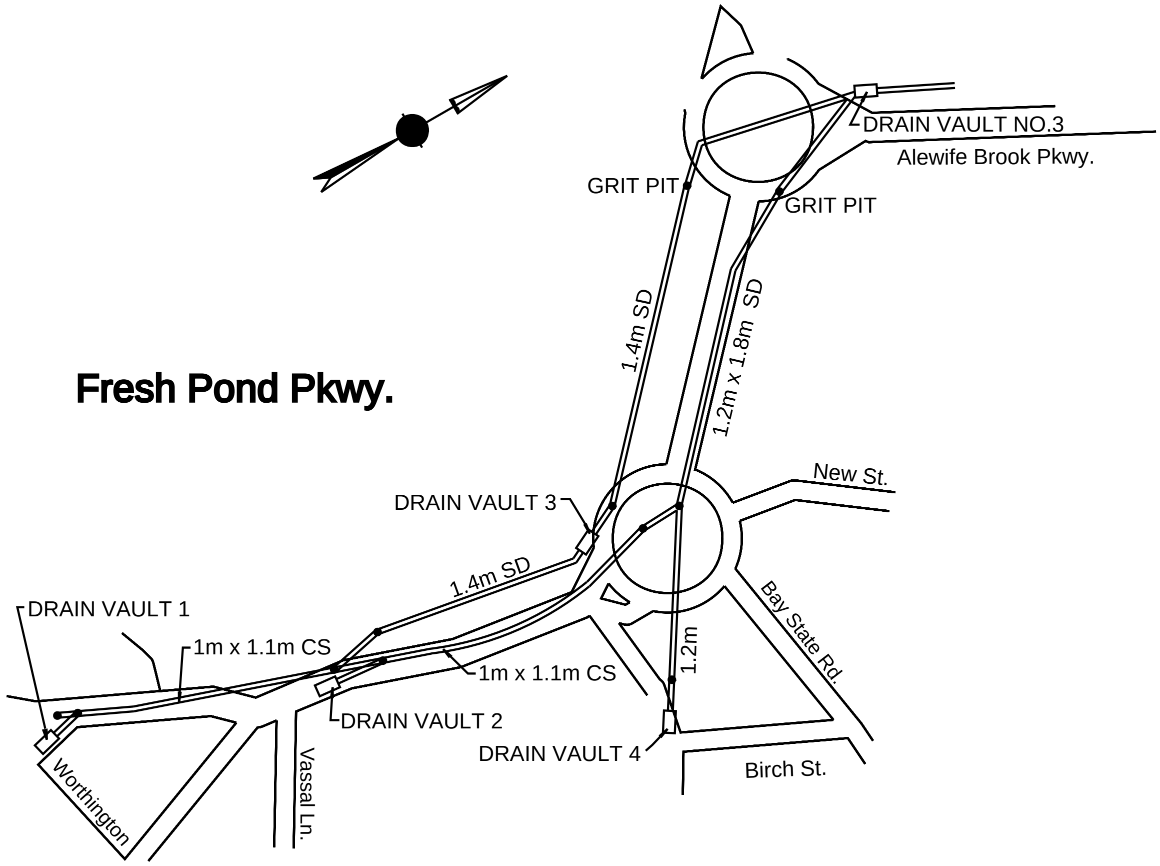

Figure 7-1. Fresh Pond Parkway - Locations of Flushing Vaults

Description of Flushing Vaults

Another alternative is to retain pipes with flat slopes, but provide periodic cleaning of these pipes by automatic passive means to maintain hydraulic capacities. The use of flushing chambers at specific locations, with grit collection chambers downstream were designed for the Fresh Pond Project. The design utilized quick opening flushing gates (hydraulically driven) that release stored water to create a “dambreak” flush wave to cleanse and move sediments downstream to a grit pit. Several hundred such installations have been implemented in Western Europe since 1985.

Figure 7-2 shows a typical storm sewer flushing chamber with quick opening gate designed for the City of Cambridge. During a rainfall event, stormwater from the incoming storm drain fills the sump adjacent to the flush chamber. Submersible pumps then pump stormwater from the sump into the flush chamber. Each flush chamber volume was sized based on the roughness, slope, size and length of the pipe being flushed. The “flush wave” is designed to have a depth of approximately 100 to 150 millimeters (4 to 6 inches) and a velocity range between 0.9 to 1.2 meters/second (3 to 4-feet/second) at the end of the pipe segment being flushed. Once filled, the pumps shut off and a timer is initiated that automatically initiates the flushing sequence 24 hours after the rain event.

Process water (back wash) from the new Cambridge water treatment plant will be pumped to the new sanitary system and collected in sanitary sewer flushing vaults for periodic flushing of the sanitary sewers.

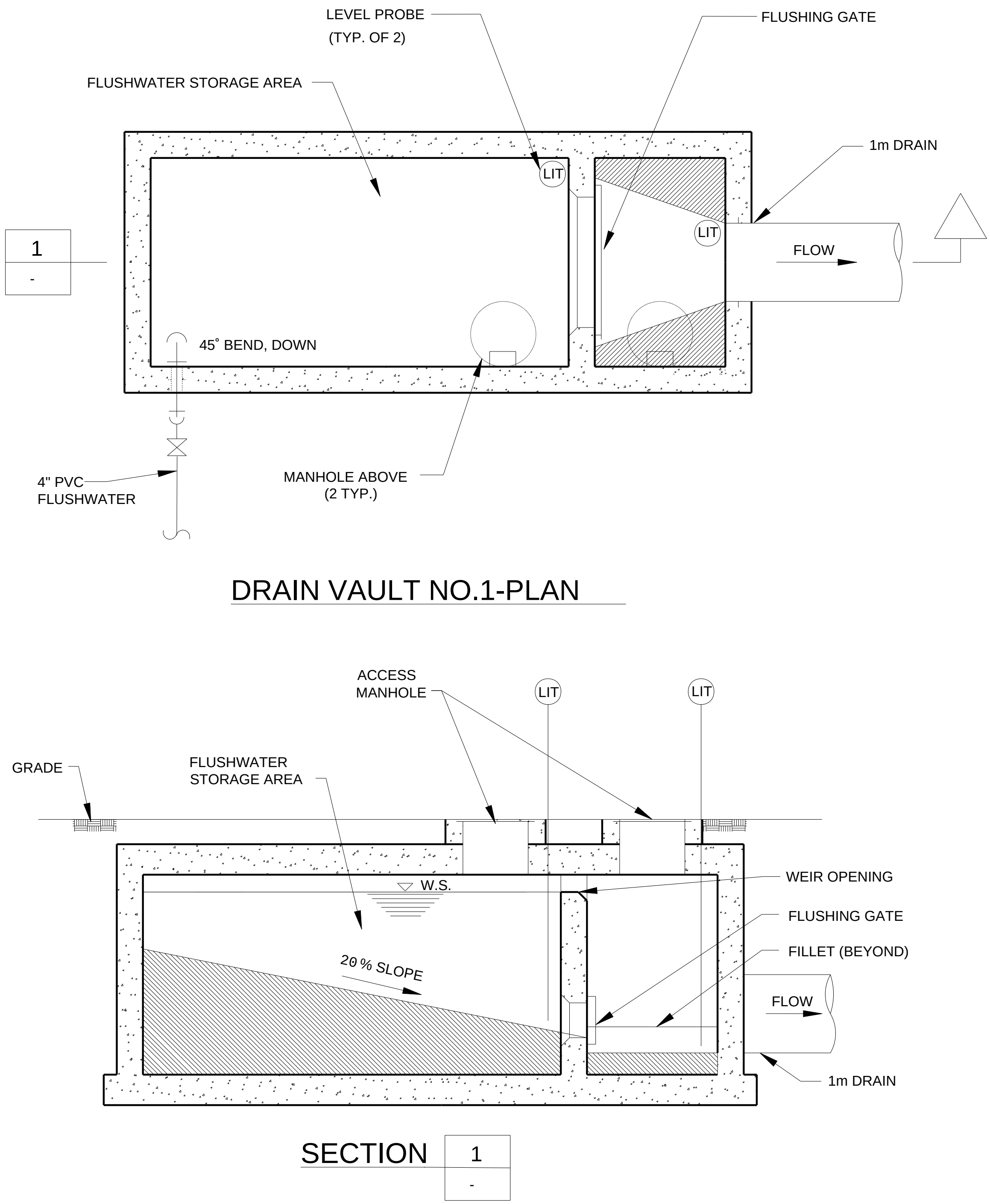

Figure 7-2. Fresh Pond Parkway - Flushing Gate Chamber

This approach is intended to minimize the daily operation of the system and provide the flexibility of cleaning the pipes on demand. It would be cost-effective due to reduced initial capital costs and minimal long term operational and maintenance costs versus a typical pumping station that requires daily maintenance and power.

Life Cycle Cost Comparison: Automated Flushing versus Periodic Manual Removal

This preliminary analysis presents life cycle costs for two alternative systems to clean the major storm and sanitary systems described above over a thirty-year period. Catch basin cleaning and cleaning of all incidental lateral lines tributary to both systems were not included. The cost of each alternative system does not include estimates of materials to be removed and disposed. Notwithstanding this limitation, all costs necessary to remove deposits to street level using either scheme are included.

Details of the Automated Flushing Systems

The automated flushing scheme consists of the following three separate flushing and grit capture systems:

- Near the new water treatment plant on Fresh Pond Parkway to the Concord Circle (sanitary and storm) including costs of collector manholes for the storm lines. Daily flushing of the sanitary system and periodic flushing of the storm system (assumed every two weeks; flush vaults are filled using captured stormwater);

- Concord (Sozio) Circle to the Fresh Pond Circle (sanitary and storm) including the cost of collector manholes for the storm system. Daily flushing of sanitary system and periodic flushing of storm system (assumed every two weeks; flush vaults are filled with pumped captured stormwater);

- Fresh Pond Circle to the south side of the B&M railroad crossing at the site of a new grit and sand collector area. The storm drain and both sanitary trunk sewers will be flushed. Twice weekly flushing of sanitary systems and periodic flushing of storm system (assumed every two weeks); flush vaults are filled with pumped captured stormwater);

The capital costs of the flushing systems include the flushing vaults, the grit capture chambers (storm only), small above ground vaults to house the hydraulic power pack units to trigger the flushing systems, and chambers as appropriate to pump storm water into the flushing chambers. External flush water (stormwater runoff) will be used to flush the sanitary systems from the Fresh Pond Circle to the Alewife rotary garage. The additional cost of sewage treatment of added flushwaters was included for the two sanitary sewer chambers at Fresh Pond Circle. Approximately 757,060 liters (200,000 gallons) are needed for flushing on an annual basis. No such costs are included for the storm system, as collected storm water will be used to flush the storm lines. Incidental costs of pumping storm water to flushing vaults are included. It is assumed that on a quarterly basis all vaults will be cleaned of collected materials. Trucking and disposal costs are not included. Police detail costs are also not included. Pertinent summary details of the flushing systems are given in Table 7-1.

Table 7-1. Flushing System Summary

Location	Pipe Service	Pipe Diameter (meters)	Flushing Segment Length (meters)	Flushing Volume (liters)
Drain Vault #1	Drain	0.91, 1.06, 1.37	390	12,083
Drain Vault #2	Drain	1.06	235	9,725
Drain Vault #3	Drain	1.37	240	10,917
Drain Vault #4	Drain	1.22, 1.22 by 1.83	350	12,655
Drain Vault #5	Drain	1.83	443	39,640
Sanitary Vault #1	Sanitary	0.4	215	5,845

Sanitary Vault #2	Sanitary	0.6	350	6,363
Sanitary Vault #3	Sanitary	0.4	426	9,202
Sanitary Vault #4	Sanitary	1.22	426	24,059

Table 7-2 summarizes the life cycle costs for sanitary and storm sewer flushing vaults for the locations noted above. Present worth costs per gallon flushing volume averaged about $44 per liter ($165 per gallon).

Details of the Manual Cleaning System

It is assumed that the sanitary systems will be cleaned on a three year cycle and the storm lines cleaned on a five-year cycle. Existing sediment levels (about one-third of pipe depths) can reoccur in a five year period (estimated).

Unit cleaning costs were obtained from contractor bids for the cleaning construction package of the storm and sanitary sewers within the project area as follows:

- 914 mm (36 inch) Storm Drain -$75.00/meter ($25.00/foot)
- 1067 mm (42 inch) Storm Drain -$102.00/meter ($34.00/foot)
- 1219 mm (48inch) Storm Drain -$129.00/meter ($43.00/foot)
- 1372 mm (54 inch) Storm Drain -$163.50/meter ($54.50/foot)
- 1829 mm (72inch) Storm Drain- $267.00/meter ($89.00/foot)
- 1.22 m x 1.83 m (4'x 6') Storm Drain -$232.50/meter ($77.50/foot)
- 457 mm (18inch) Sanitary -$19.50/meter ($6.50/foot)
- 610 mm (24") Sanitary -$21.00/meter ($7.00/foot)
- 1219 mm (48") Sanitary -$60.00/meter ($20.00/foot)

No trucking and disposal costs are assumed. On a life cycle basis, the automated flushing scheme is about $400,000 cheaper. The reader must also be aware that the avoidance of potential real and societal costs of flooding caused by surcharged and clogged drains and sewers is not reflected in this cost estimate. In addition, the nuisance level costs associated with traffic disruption on Fresh Pond Parkway (4 lanes with 50,000 vehicles per day) are also not reflected. An independent estimate of traffic disruption places a present value of $3 million. Last, the analysis does not take into account the fact that even after separation is completed, overflows can occur at the end of the sanitary system which is 2 kilometer (1.2 miles) downstream. Periodic flushing of the sanitary sewer trunk lines will minimize the amount of scoured and suspended solids discharged from this overflow into Alewife Brook during major wet periods.

Table No. 7- 2. Cost Effectiveness Analysis Flushing versus Manual Cleaning

Manual Pipe Cleaning	Present Worth Cost ($M)	Flushing Chamber Sites	Present Worth Cost ($M)
Sanitary Sewer Cleaning	0.9	Fresh Pond Circle Site	1.1
Storm Drain Cleaning	3.4	Concord Circle Site	1.5
---		Water Treatment Plant Site	1.3
Total	4.3	Total	3.9

Notes:

1. Pipe cleaning costs assume inflation rate of 3.12% per year.

2. Stormwater pipes are cleaned every 5 years, and sanitary pipes are cleaned every 3 years.

3. Flushing costs are based on inflation rate of 3.12% per year and discount rate of 7.1% per year.

4. Term = 30 years

5. Flushing costs for the sanitary systems include payment to the MWRA for all external applied flushing water. The annual flush waters for the sanitary systems = 757,060 liters (200,000 gallons). Current cost factor of $5.68/3,785 liters (1000 gallons) used.

6. Maintenance labor cost = $60/hour.

7. Sanitary systems to Fresh Pond Circle assumed to be flushed.

8. Storm systems will be flushed approximately every two weeks depending on rainfall.

9. Capital costs for flushing sites include excavation and backfill, hauling, pavement, gravel, dewatering, hazardous soil disposal, piping, traffic maintenance, equipment, structures and mobilization.

10. Operation and maintenance costs for flushing sites include hydraulic oil, routine inspection and servicing, power, and removal of collected sediments. Trucking and disposal costs are not included.

Case Study Two: Cost Effectiveness of Sewer Flushing versus Conventional Treatment

Over the last two decades, numerous investigators have noted that routine flushing of flat sewers on a continual (i.e., one to three day interval) basis could decrease the amount of solids available for scour, resuspension and transport to overflows. Until recently, flushing equipment has not been available to accomplish this idea in practice.

This case study investigates the cost effectiveness of utilizing the flush gate technology to flush on a routine basis sewer deposits within a large flat sewer to minimize “first flush” at a downstream overflow. The alternative conventional approach would be to use a satellite treatment facility such as a retention or detention treatment tank or vortex separator technology. The basic idea is to ascertain whether flushing on a routine basis can be a cost-effective adjunct to other treatment schemes or even viewed as a stand-alone control.

The case study is developed from actual data in a Northeast community. The first step in the investigation is to compute solids loadings in the overflow over the course of a year. Life cycle costs to handle these loadings using satellite CSO treatment are next computed. Next, flush gate technology is used to flush on a routine basis the same flat stretch of sewer, thereby reducing the amount of available solids that would be scoured and carried out the downstream overflow during high flow events. Life cycle costs are computed for this alternative “preventative” scheme and compared with the costs involved with satellite treatment.

Description of Area

The sewer catchment covers an area of 1600 hectares (4000 acres). The land use is mixed with a portion of heavy industrial and food processing establishments. The sewers are old, separated and carry heavy inorganic and organic settleables solids loadings. Inorganic loadings generally inflow from cracks in sewer and manholes. Organic loadings derive from food processing wastes, average about 15 mg/l, and are generally large rapidly settling particles.

Flow monitoring data collected at the end of the catchment prior to entry into a 1.8 m (72 inch) line were used as input to the desktop procedure. A summary of the input flow data is presented below Statistics of the average daily velocity, average, maximum hourly velocity, average daily and average peak hourly shear stress levels within the 1.8 meter (72 inch) sewer are presented in Table 7-3.

Overflow at the downstream regulator occurs when hourly flow levels exceed 2632 lps (60 MGD). The desktop procedure notes events occurred when the average daily flow rate exceeded 2632 lps (60 MGD) or when the peak hourly flow rate was less then 2632 lps (60 MGD). A summary of the events including number of activation's, peak overflow rate and total volume of overflow are listed below in Table 7-4. There are 21 events with a total annual overflow volume of 676,400 cubic meters (178 million gallons). Overflow peaks range up to 877 lps (20 MGD). The organic settleable solids input to the outfall line from the catchment is 879 metric tons (970 tons). During the 21 overflow events, about 230 metric tons (256 tons) of organic solids discharge to the receiving water (average concentration equals 290 mg/L.)

Table 7-3. Average Daily and Average Maximum Hourly Velocity and Shear Stress

Average Daily Velocity:	0.70 m/s (2.3 fps)
Average Maximum Hourly Velocity:	0.85 m/s (2.8 fps)
Average Daily Shear Stress:	0.84 N/m^2
Average Maximum Hourly Shear Stress:	1.2 N/m^2

Table 7-4. Pertinent Overflow Characteristics

Number of Overflows:	21
Total Volume Overflow:	676,400 m^3 (178 MG)
Range Overflow Discharges:	43 to 868 lps (1-20 MGD)
Total Hours Activation:	228 hour
Total Organic Settleable Solids:	232,000 kg (512, 200 lb) Loadings in Overflows
Total Organic Settleable Solids:	881,000 kg (1,938,000 lb) Input to System
Average Concentration:	290 mg/l Organic Settleable Solids overflow
Average Daily Input:	15 mg/l Organic Settleable Solids

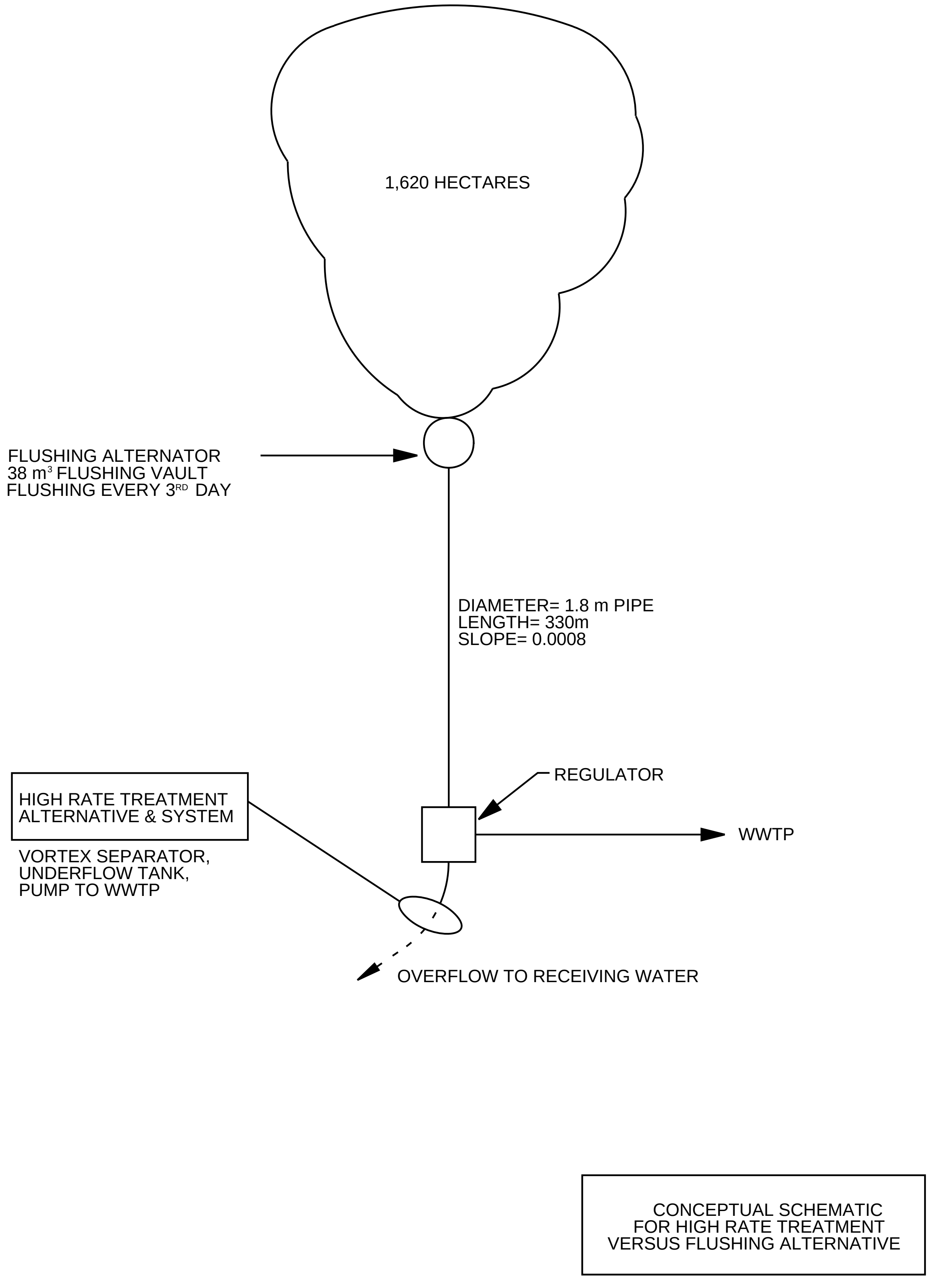

Figure 7-3. Conceptual Schematic for High Rate Treatment.

A conventional satellite treatment at the overflow facility consists of a vortex separator and underflow storage facility. A conceptual schematic of alternative controls are depicted in Figure 7-3. A satellite treatment system to handle the 21 overflows is assumed. The facility consists of a 9 meter (30 foot) diameter vortex separator, a 760 cubic meters (0.2 million gallon) underflow tank (sized to retain 5% maximum overflow), headworks including course screening, dewatering pumps (both vortex separator and underflow tank need pumping to WWTP after events), electrical and instrumentation controls, and general site civil and yard piping. Capital and operational costs were estimated for the facility using a procedure previously developed and used for CSO facility planning in Cincinnati and Toronto.

Present value costs for this configuration are shown below:

Capital	$ 2,620,000
O & M	$49, 000 /yr
Present Worth Cost	$3,150,000 (i = 9%, 30 years)

Estimated effectiveness of this satellite facility is depicted in below. It is assumed that the vortex separator will remove 75% of the incoming organic settleable solids. The maximum influent applied hydraulic loading is 8.5 lps/m^2 (12 gpm/ft^2) during the 21 overflow periods. Average applied loading on the separator is 6.6 lps/m^2 (9.3 gpm/ft^2). Vortex separators are typically designed to remove heavy settleable solids with hydraulic loadings typically in the 14 to 21 lps/m^2 (20 to 30 gpm/ft^2) range. High performance is expected in this case study.

In an alternative scheme, an off-line flushing module just upstream of the 330 m (1000 ft) reach of 1.8 m (72 inch) pipe having with a flush volume of 38 cubic meters (10,000 gallons) is programmed to flush during night hours every three days except when flows are above average in the trunk sewer (wet overflow periods). It is assumed that the flush wave on each day of flushing will move 80 percent of the existing sediment build up (noted in the desktop procedure) to the regulator and pass to the downstream WWTP.

This flushing scheme is primitive but efficient. The summary results using the desktop procedure including the flushing scheme are shown below in Table 7-5. This simple scheme reduces the annual organic settleable solids in the overflow by 92.8%. These solids would have to otherwise be handled during wet periods by the satellite treatment scheme. As stated above, the fixed interval-flushing scheme could be modified to include more intelligent options such as more frequent flushing during extended dry periods when severe deposition is occurring. Such schemes could easily be programmed.

Table 7-5. Comparison Satellite Treatment Versus Automatic Flushing

Satellite Treatment Alternative

Number Overflows:	21
Organic Settleable Solids Overflow:	232,700 kg/yr (512,200 lb./yr)
Organic Settleable Solids Removable by Satellite Treatment :	174,600 kg/yr (384,150 lb/yr) (Assume 75 % Capture)
Residual Organic Settleable Solids:	58,200 kg/yr (128, 050 lb/yr) out to receiving water

Automatic Flushing Alternative

Residual Organic Settleable Solids overflow:	16,490 kg/yr (36,280 lb/yr)
Organic Settleable Solids to WWTP:	216,300 kg/yr (475,920 lb/yr) instead of overflow (i.e., attributable to flushing)
Percent Reduction of Organic Settleable Solids loadings Attributable to flushing:	92.8%

As noted in the Case 1 Study examining flushing vaults in the Fresh Pond Parkway project in Cambridge, the average present worth per gallon of flushing vaults equals $44 per liter ($165 per gallon) The largest flush scheme proposed in the Fresh Pond Project was an 42 m^3 (11,000 gallons) vault flushing 427 m (1400 ft) of 1.8 m (72 inch) storm drain.

Using this estimate the present worth cost for the 42 m^3 (11,000 gallon) flushing scheme assumed in this case study is $1,760,000. The summary cost effectiveness comparison of the two technologies are noted below in Table 7-6.

Table 7-6 - Present Worth Cost Comparison – Flushing Gate vs. Satellite Treatment

	Effectiveness (% Capture)	Present Worth
Satellite Treatment	75%	$3,150,00
Flush Gate Technology	92.8%	$1,760,000

It is evident that the flushing scheme utilizing the flush technology appears to be more cost effective than conventional high rate satellite treatment.

Case Study Three: Cost Effectiveness of Sewer Flushing versus Chemical Addition for Hydrogen Sulfide Control

General

Hydrogen sulfide will be produced as previously discussed in Chapter 3 in sewers with an anaerobic environment and an active slime layer. Sediment accumulations can further increase the generation of dissolved hydrogen sulfide. Hydrogen sulfide can be treated in a dissolved state or as a gas once it is stripped from wastewater. The analysis in this section will focus on treating dissolved sulfide because dissolved sulfide treatment will ultimately reduce the quantity of hydrogen sulfide that is stripped from solution. This section presents a cost analysis of chemically treating dissolved sulfide within a long, flat depositing sewer for a city in the southern United States with high BOD, high volatile solids, and elevated wastewater temperature. Flush gate technology will be used to minimize sediments, thereby reducing hydrogen sulfide contributions generated from the deposited solids.

The sewer solids deposition and erosion procedure described in Chapter 4 is used to compute daily solids deposition levels. Once the annual history of deposition and erosion of solids has been computed using this procedure, dissolved hydrogen sulfide levels are next computed. First, dissolved hydrogen sulfide levels are computed for the slime layer covering the perimeter of the pipe. Pomeroy's method is used and is described in Chapter 5. Next, dissolved hydrogen levels are computed attributable to accumulated sediments. In the initial deposition and erosion calculations, surface area for each sediment size remaining on a given day is tallied. Total sediment surface area is computed on a daily basis. In the dissolved sulfide calculations, a portion of the surface area of sediments is used within the Pomeroy formulation to calculate the incremental gain of dissolved hydrogen sulfide attributable to the sediment layer. The total dissolved hydrogen sulfide levels at the end of the pipe segment is the sum of the initial levels entering the pipe segment, the increment attributable to the slime layer, and if present, the additional increment associated with the sediments.

Chemical Treatment of Dissolved Sulfide

Numerous chemicals can be used to treat dissolved sulfide through oxidation, precipitation, or preventing sulfide formation. These chemicals include pure oxygen injection, hydrogen peroxide, chlorine, potassium permanganate, nitrate solutions, and iron salts. Chemicals must provide sulfide treatment from the point of application to the WWTP for this case study comparison. Following are descriptions of each of the potential chemicals and their potential application for this case study.

Pure Oxygen

Pure oxygen or air can be added to sewers to oxidize dissolved sulfide. However, more than one injection point is required for prolonged treatment of dissolved sulfide because of the tremendous oxygen uptake demand of the wastewater and slime layer. This option is not considered for the case study comparison because more than one injection point is required to treat dissolved sulfide along the length of sewer.

Hydrogen Peroxide

Hydrogen peroxide can oxidize hydrogen sulfide very quickly but it is a non-specific oxidant and will oxidize other compounds beside sulfide. However, peroxide is only effective up to 45 minutes after application before it decomposes to water and oxygen. Hydrogen peroxide is dangerous to handle in high concentrations and hazardous to humans. It would require specific chemical storage and handling equipment procedures, as do most of the oxidizing odor control chemicals. Hydrogen peroxide is not recommended for this case study because of its quick decomposition after application.

Chlorine

Chlorine could also oxidize the same compounds as peroxide but the longer half-life and toxic nature of chlorine would prohibit dosing large slugs of the chemical required to be effective. Chlorine would also react with organics to produce a variety of chlorinated organic compounds (chloroform, formaldehyde and other mono and polysubstituted chlorinated organic compounds of indeterminable chemical composition). These compounds could then, depending upon the physical and chemical properties, be released at downstream processes. Chlorine is also hazardous to handle and requires strict adherence to health and safety procedures and is not considered the most desirable alternative for this case study.

Potassium Permanganate

Potassium permanganate could be used but the production of manganese dioxide from its use and the batch nature of the chemical mixing process would make it a difficult system to operate. Potassium permanganate is also a hazardous chemical to handle and has explosion precautions for contact with dry powder. Permanganate application would require particulate control during mixing and personnel respirators must be worn during mixing. This is also the most expensive chemical (on a per pound of sulfide removal basis) to use for sulfide removal and is not considered appropriate for this

Nitrate Solution
Nitrate, if provided in sufficiently high concentrations directly onto the solids in the siphon, would have the effect of suppressing or stopping sulfide production in the upper layers of the sediments. Bacteria will use free oxygen first, then reduce nitrate before reducing sulfate. Therefore, if nitrate is present the bacteria will not reduce sulfate to sulfide. This would reduce, although not eliminate, the evolution and release of hydrogen sulfide at the treatment plant. Nitrate can not act quickly enough to be of much use over the entire length of the siphon and an overdose could violate discharge requirements or cause bulking in the secondary clarifiers at the WWTP However, the massive logistical effort and cost of applying that much nitrate uniformly to the siphon is impractical.

Iron Salts
Iron salts will react with dissolved sulfide to form metal-sulfide precipitates. The metal-sulfide floc typically does not settle in the collection system because of its characteristics and is often removed in the secondary treatment stage of a WWTP. A metal salt residual can be maintained in the collection system and effective sulfide control can be accomplished up to 40 kilometers from an application point with the proper environment. Because of these reasons the case study cost analysis was performed using iron salts to treat the anticipated dissolved sulfide loading.

Flushing Gates for Sulfide Reduction
As discussed in Chapter 4, flushing gates are used to periodically clean pipes that can accumulate sediment. However, sediment in collection systems can also contribute and actually increase hydrogen sulfide production. Therefore, if a flushing gate is installed on a segment of a collection system to keep the pipes relatively free of debris then the corresponding sulfide generation should decrease.

Case Study Description
The case study in this section represents a city located in the southern part of the United States. Cities in this part of the country typically have wastewater characteristics with high BOD concentrations and elevated temperatures that can lead to substantial hydrogen sulfide concentrations (when compared with locations in cooler climates). The specific mean and maximum wastewater characteristics for this case are contained in Table 7-7.

Table 7-7. Wastewater Characteristics

Parameter	Average Daily	Average Daily Maximum	Average Daily Minimum
Discharge (lps)	3468	6571	2707
BOD5 (mg/l)	570	928	197
VSS (mg/l)	376	760	39
TSS (mg/l)	464	913	272
Temperature (deg. C)	29	32	16

The desktop procedure described in Case Study 2 was used to analyze a 1.8 m diameter sewer. This procedure calculated sediment and erosion behavior, calculated dissolved sulfide concentrations using the Pomeroy method described in the Chapter 4, and calculated dissolved sulfide attributed to the accumulated sediments. The sewer is 915 meters long and has a slope of 0.0007. The dissolved sulfide concentration entering the pipe was assumed to be 0.25 mg/l. It is assumed that the allowable dissolved sulfide concentration entering the WWTP is 0.75 mg/l. Three 50 m^3 gallon flush gates must be installed to clean the 915 m long conduit (flush gates are spaced equally along the pipe length to clean 305 meters each). The flush gates are programmed to flush every third day during low flow conditions.

Based on the above information the desk-top procedure revealed that 383,750 kilograms of sulfide was produced in this segment of the sewer per year. Approximately 208,200 kilograms of sulfide was produced in the sediment layer of the siphon and the remainder was attributed to the slime layer on the pipe walls.

Cost Analysis

Two conditions were analyzed for this case study; 1) treating the yearly hydrogen sulfide mass with chemicals and 2) using a combination of flushing gates and chemicals to treat the total sulfide mass. Present worth calculations will be estimated for both scenarios.

Iron salts are assumed to treat the dissolved sulfide concentration for this sewer segment. Specifically, ferrous chloride will be used for the analysis. Ferrous chloride solution has approximately 0.12 kilograms of iron per liter of solution and a capital cost of \$0.16/liter. Field experience indicates that approximately 0.82 kilograms of iron is required to treat 0.45 kilograms of sulfide. Therefore, the general cost of treatment per kilogram of sulfide is approximately \$2.42. The capital cost for the chemical addition equipment is approximately \$50,000 (installed) and the yearly operation and maintenance cost is \$10,000. The flushing gate systems are based on a flushing vault volume of 50 m^3 and a present value cost of \$35,200/m^3. Costs assume an inflation rate of 3.12% per year, discount rate of 7.1%, and a 30-year term.

Condition 1 - Sulfide Treatment with Ferrous Chloride

The estimated present worth cost for treatment of 383,750 kilograms of dissolved sulfide per year (assuming that sediment contributes to the total sulfide mass) is \$15.5 million.

Condition 2 - Sulfide Treatment with Ferrous Chloride and Flushing Gates

This condition assumes that the total sulfide mass contribution from the sediment (208,200 kg) bed is eliminated by using the flushing gates to minimize sediment accumulation in the pipe. The estimated present worth cost for treatment of 175,900 kilograms of dissolved sulfide per year using ferrous chloride to treat the dissolved sulfide and plus the present worth cost of the flushing gate system to minimize the sulfide formation is \$12.5 million.

Summary of chemical treatment costs and flushing gate costs for both conditions are shown in Table 5-10.

Table 5-10. Chemical Treatment Costs

	Chemical Cost (\$)	Flushing Cost (\$)	Total Cost (\$)
Condition 1	15,500,00	N/A	15,500,00
Condition 2	7,200,000	5,200,000	12,500,000

It appears that the overall system of employing flushing in combination with chemical treatment of residual unacceptable dissolved hydrogen sulfide levels is cheaper than only chemical treatment.